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Anchorage Capacities in Thick Coal Roofs

By Stephen C. Tadolini

UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 9058

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UNITED STATES DEPARTMENT OF THE INTERIOR
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	lb/in^3	pound per cubic inch
in	inch	µin	microinch
lb	pound	psi	pound per square inch
lbf·ft	pound (force) foot		

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ANCHORAGE CAPACITIES IN THICK COAL ROOFS

By Stephen C. Tadolini [1]

ABSTRACT

The anchorage capacity of four types of bolting systems was investigated in two mines with thick coal roofs. In conjunction with the in-mine tests, a simple axisymmetric finite element computer program was developed. Both the field and computer results indicated that thick coal roofs can be effectively supported entirely by the coal member.

INTRODUCTION

Many coal mines in the Western United States are located in thick coal seams that often leave the mining operators several feet of coal to form the mine roof. Information is needed concerning effective roof support in such mines. In this investigation of bolt anchorage capacities in thick coal roof, the following parameters were investigated:

1. Type of anchorage--mechanical or chemical, either fully or partially bonded, using resin or cement as the bonding agent.
2. Length of anchor--short (4 ft or less), medium (4 to 6 ft), or long bolts (6 ft or more).
3. Diameter of anchor--small (less than 0.5 in), medium (from 0.5 to 1.0 in), or large (greater than 1.0 in).

To establish basic support criteria for mines with thick top coal, various types of roof bolts were investigated in small-scale in-mine tests. The bolts were pull tested to determine the average amount of support capacity that could be expected. In conjunction with this field investigation, a simple axisymmetric finite element model was developed to simulate pull tests. The model simulated a 3/4-in-diam bolt installed in a 1-in-diam hole in a thick coal roof. To ensure equilibrium and compatibility, deformation lengths were predetermined using strain-gauge bolts. The information obtained from the pull tests was compared with data derived from the finite element model to provide a fundamental approach for designing an adequate support system for thick coal roofs.

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The author expresses gratitude to the Consolidation Coal Co. and Valley Camp of Utah Inc. for their continued support of ground control research. Special thanks are extended to Steven Jaccaud, superintendent of Consolidated's Emery No. 50 Mine, Emery, UT, and Virgil Lamb, superintendent of Valley Camp's Belina No. 1 Mine, Scofield, UT, who made available personnel and equipment for this study.

PULL TEST: A METHOD FOR DETERMINING THE STRENGTH OF A ROCK BOLT ANCHOR

Pull tests were conducted in two mines. In the first mine, a total of 40 bolts of four different types were tested. The four types were--

1. Atlas Copco Swellex,[2] a bolt that is expanded by high water pressure,
2. Combination resin-grouted and mechanical bolts,
3. Mechanical expansion anchor bolts, and
4. Resin-grouted bolts.

The bolts were installed in a roof that consisted of 8 ft of coal as predetermined with a fiber-optic stratascope. Various torque and expansion pressures were used, except that these parameters did not apply to the resin-grouted bolt installations. In the second mine, only fully resin-grouted bolts were tested, again in a roof with thick top coal. Pull tests were performed on each bolt to determine the bolting effectiveness of each individual bolt type.

The pull test is intended to measure the strength of a rock bolt anchorage system under field conditions. This is based on the premise that the best way to compare data obtained from anchorage tests is to analyze the load-deformation curve produced from plotting field information. However, information obtained from pull tests performed on full-column grouted bolts reveals very little about anchorage capacity. Tests on such bolts usually determine only the strength of the steel used to manufacture the bolt. This makes it imperative that shorter grout columns be investigated to determine actual anchorage capacities.

CHARACTERISTICS OF ROOF BOLTING SYSTEMS

Roof bolts have become an essential means of support in all types of underground openings. Numerous types and configurations of bolts are presently utilized to support excavations under all types of conditions.

Previous investigations have involved both the developmental and evaluation stages of virtually all roof support devices (1-4).[3] In this investigation, pull tests were conducted on the four types of bolts previously mentioned. These bolt types are illustrated in figure 1. Strain-gauge bolts were also pull tested. The bolt types tested are not the only types deemed to be acceptable; they were, however, the bolts being considered by mine operators in the area where the tests were conducted at the time of the investigation.

All bolt characteristics discussed in the following sections are minimum laboratory values. In some cases, the characteristics vary from bolt to bolt.

ATLAS COPCO SWELLEX SYSTEM

The Swellex water-pressure expansion bolt is manufactured from steel pipes

[2]Reference to specific products does not imply endorsement by the Bureau of Mines.

[3]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

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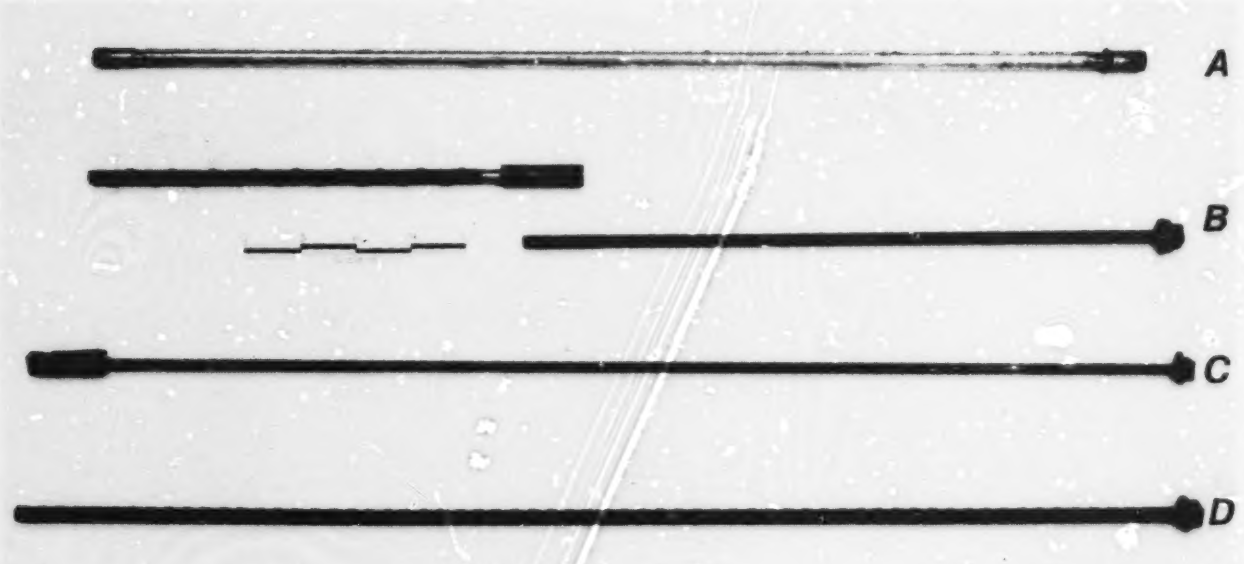

FIGURE 1. - Tested roof bolts. *A*, Atlas Copco Swellex; *B*, combination; *C*, mechanical expansion anchor; *D*, resin grouted.

with a 1.61-in OD and a 0.08-in wall thickness. The pipes are reshaped to the Swellex profile with a 1.00-in OD as shown in figure 2. The bolt ends are strengthened with short support sleeves and sealed with welds. A small hole in the outer end of the bolt allows a high-pressure pump to inject water into the bolt, which then expands in the borehole, as schematically shown in figure 3. The bolt starts to expand at 880 to 1,180 psi. This expansion pressure causes the shell of the tube to deform plastically around irregularities in the borehole wall, thus creating a strong mechanical bond between the bolt and the rock.

The Swellex bolt also works in smooth and straight (diamond-drilled) boreholes. Anchoring is achieved as a result of the high water pressure being transmitted to the borehole wall and causing the bolt and rock to expand elastically a few hundredths of an inch. After installation, when the water pressure is released (and the water flows out of the injection hole in the outer end of the bolt), rock relaxation is prevented by the expanded bolt, resulting in a residual pressure between the bolt and the borehole wall. The configuration of the expanded bolt combined with its material properties creates a spring action.

An additional support characteristic of the bolt is its ability to provide active support. As the bolt is expanded, a small reduction in length occurs in the lower portion of the bolt. This creates tension in the bolt, which holds the bearing plate firmly against the rock. However, the resultant pressures can fracture brittle rock. This fracturing can be prevented by sliding a short tube over the bolt to prevent expansion of the bolt near the collar of the hole (5).

COMBINATION SYSTEM

The combination bolt utilizes resin-grouted rods for anchorage and mechanical bolts for tensioning the bolting system. The combination bolts used in this study consisted of a 2-ft length of 7/8-in-diam rebar coupled with a 3-ft length of 5/8-in-diam grade 55 steel (12,400 lb yield and 19,200 lb tensile strength). The

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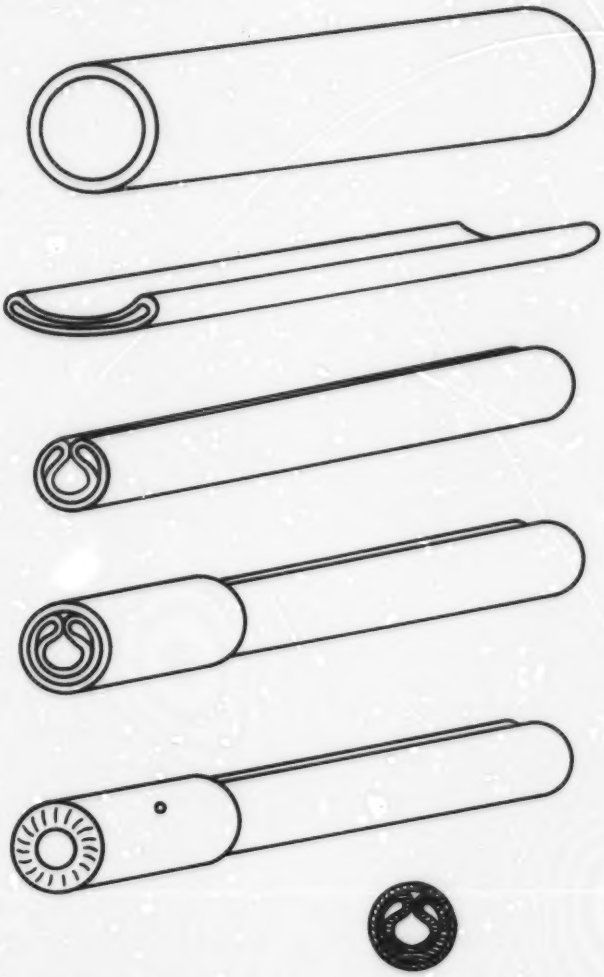

FIGURE 2. - Atlas Copco Swellex bolt manufacturing sequence.

physical distinction of the combination system is the length of the resin anchor--24 in or greater. The anchor encases a threaded joint in which the mechanical bolt can be inserted. The resin-grouted portion of the combination system not only provides anchorage for the device, but also reinforces the strata like a fully grouted bolt. The mechanical portion of the system can be adjusted to exert a desired tension on the bolt. This force is traditionally measured in torque and can be varied to limit deformation or prohibit deformation entirely.

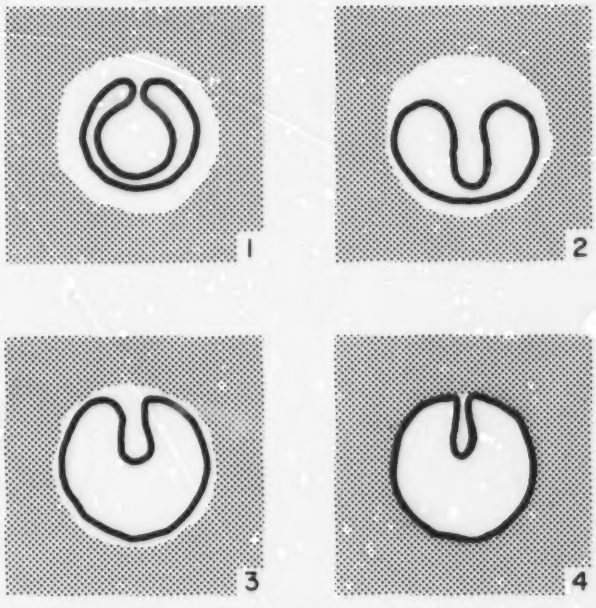

FIGURE 3. - Atlas Copco Swellex bolt expansion sequence.

MECHANICAL SYSTEM

Mechanical bolting systems utilize a split-block, wedge-type expansion shell to create anchorage and support loads generated through the tensioned portion of the bolt. The mechanical bolts used in this study were 5/8-in-diam grade 55 steel (12,400 lb yield and 19,200 lb tensile strength).

The success of a mechanical system is a function of its anchorage capacity. Traditionally, clamping loads have been restricted to one-half of the yield point or anchorage capacity of the material in order to preserve both the integrity of anchorages and the bolt itself. To ensure that proper torque levels were used in the thick top coal, torque-tension ratio tests were performed. (See appendix.)

FULLY RESIN-GROUTED SYSTEM

Fully grouted bolts rely on the mechanical interlock of the resin and interstices within the confines of the borehole wall and along the surfaces of the

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reinforcing rod to bind roof strata together. The bolts used in this study were comprised of 3/4-in-diam reinforcing steel rod, grade 40 (17,600 lb yield and 30,000 lb tensile strength), grouted in a 1-in-diam hole. No lateral forces are generated with fully grouted bolts at the time of installation, but high levels of anchorage can be expected. The horizontal reinforcement characteristics of the bolt permit it to carry high sheer-resistance values, with moderate stiffness resistance (resistance to bending).

STRAIN-GAUGE SYSTEM

Strain-gauge bolts (fig. 4) were construcetd to be pull tested in conjunction with the other bolting systems. The strain-gauge bolts used were 1-in-diam rolled rebar bolts, each with a hole approximately 0.125 in in diameter along the axis at the centerline. Six sets of strain gauges were placed on 5-ft bolts at three levels. The three gauge levels, as measured from the top of the threaded end, were 6 in, 27 in, and 57 in, respectively. A total of 10 bolts were installed with 2 to 3 ft of resin grout, enabling the strain gauges at the 27-in level to be monitored with and without resin grout. The bolts were pull tested to obtain the traditional load-displacement curve, as well as the strains measured by the gauges at 1,000-lb increments of load (6).

PULL TEST RESULTS

The bolts were installed in the test sites and pull tested approximately 24 h later. This ensured an adequate resin cure and permitted retorquing of the combination and mechanical bolts. To ensure proper anchorage, the diameters of the drilled holes were measured with a flexible hole gauge. Every fifth hole was measured at 1-ft intervals, with a maximum fluctuation of 1/16 in in diameter being deemed acceptable. The drill-hole lengths were also corrected to compensate for the 1-in pull collar that was needed at the head of each bolt. For example, a 60-in bolt was placed in a hole drilled to a depth of 59 in. Because all the support systems tested require the same pull-ring, no corrections were necessary for the subsequent analysis. The bolts were pull tested in accordance with the methods recommended by the International Society for Rock Mechanics (7). The pull test apparatus used in the investigation is represented in figure 5.

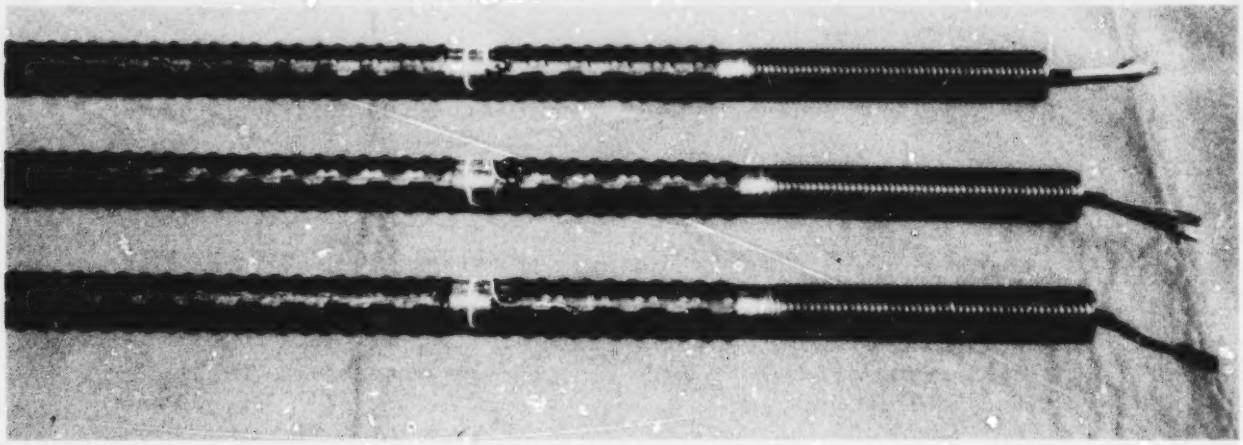

FIGURE 4. - Strain-gauge bolts.

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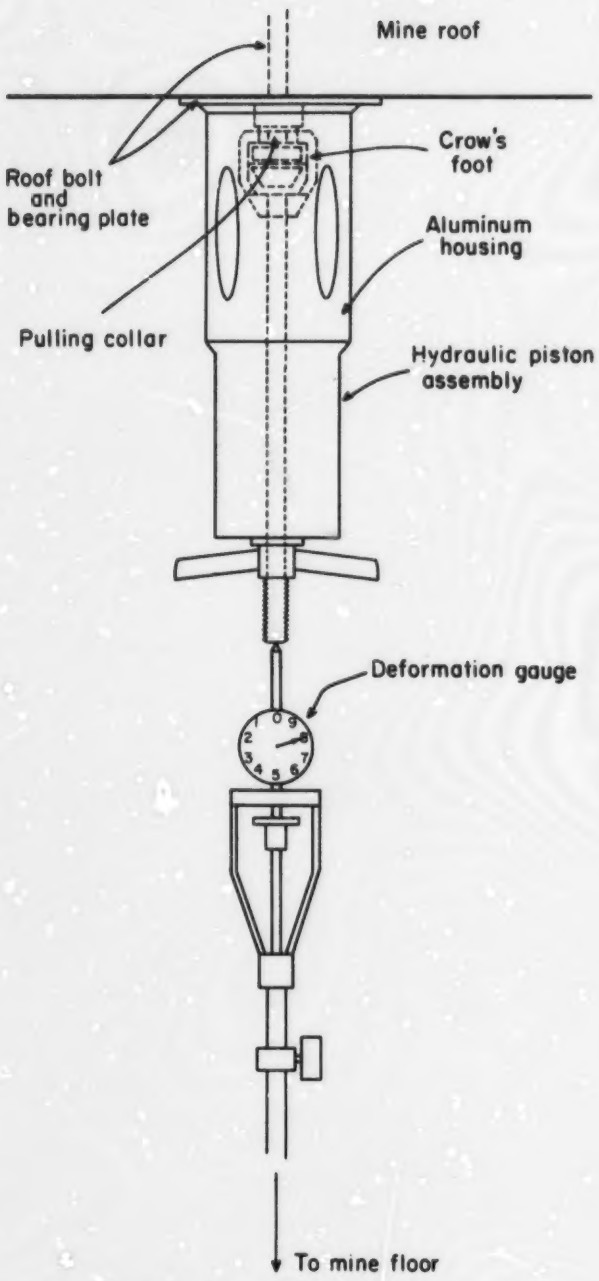

FIGURE 5. - Pull test apparatus.

ATLAS COPCO SWELLEX BOLTS

The Swellex bolts were expanded using two installation pressures--3,087 and 4,410 psi, respectively. The results varied, with the yield point for the bolts installed at 3,087 psi (fig. 6)

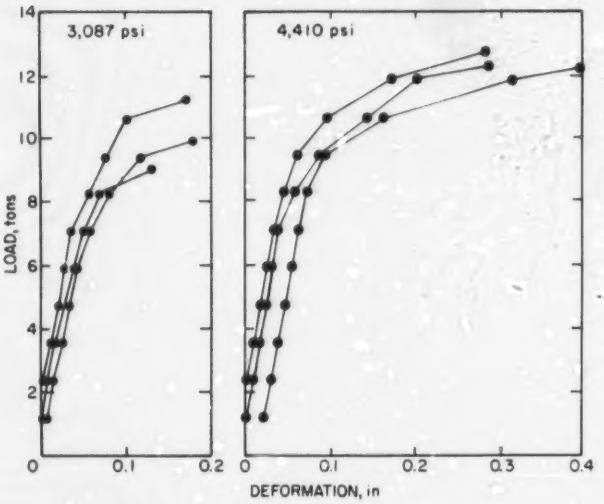

FIGURE 6. - Swellex bolt pull test results. 5-ft bolts, 1.375-in-diam holes, at installation pressures shown.

being reached at an average value of 9.5 tons. The deformation at this value was <0.1 in. The bolts installed with 4,410 psi of installation pressure yielded at an average load of approximately 11 tons.[4] The deformation at this point was also <0.1 in.

COMBINATION BOLTS

The combination bolts were installed using two different torque loads. The results of the pull tests showed that when the bolt was installed with 200 lbf·ft of torque (fig. 7), the average yield point was 10.5 tons with displacements of <0.1 in. The bolts installed with 150 lbf·ft of torque failed completely or just met the testing criteria selected for this study (8 tons of load with no more than 0.2 in displacement). Because pull tests are primarily concerned with the vertical movements related to the anchor of the bolt, these results might appear to be unreasonable upon cursory examination. All of the combination bolts were installed with identical anchors consisting of 2 ft of resin grout.

[4]In this report, "ton" indicates 2,000 lbf.

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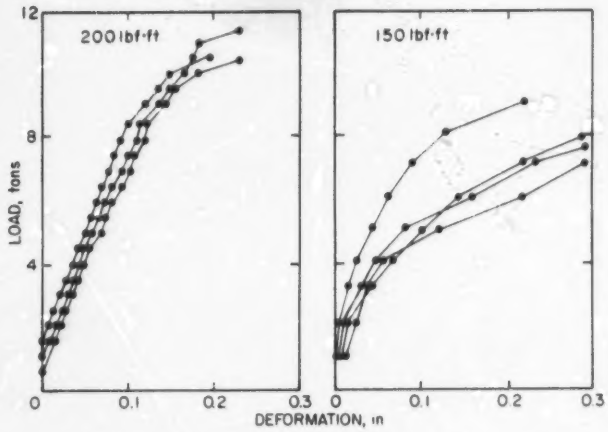

FIGURE 7. - Combination bolt pull test results. 5-ft bolts, 0.75 in diam, with 24-in resin columns, torques as shown.

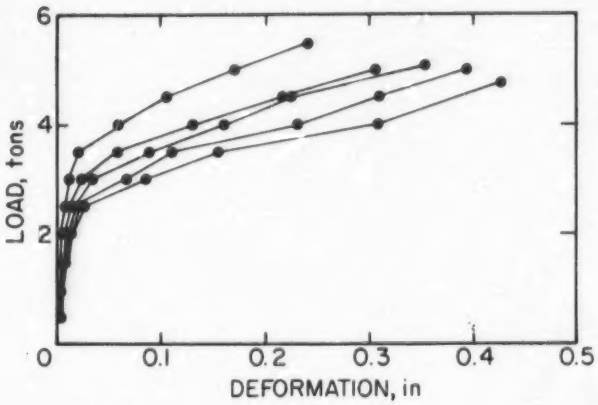

FIGURE 8. - Mechanical expansion anchor bolt pull test results.

However, if the pretensioning of the grouted length is taken into consideration, it would be possible to experience a higher level of resistance for the same increment of load for both torque levels. The grouted portion is placed into a higher degree of tension by the increased amount of force applied at the coupling. This grouted portion would, therefore, show a higher yield strength and, at the same time, less deformation.

MECHANICAL EXPANSION ANCHOR BOLTS

Mechanical bolts support the roof by suspension, friction, and keying. The effectiveness of mechanical bolting systems is determined by the quality of their anchorage in the rock. In all instances of bolt failure in the thick coal roof, the strength of the bolt was not approached, but the anchor failed (fig. 8). Even when complete failure did not occur, anchor slippage was observed. The basic cause of the anchorage problem was stress concentrations at the anchorage point. These concentrations can be effectively dissipated by increasing the contact area of the anchor by increasing its length or diameter. The coal's low compressive strength prevented most of the keying anchorage. Failures occurred at an average of 4 tons, with failure considered as >0.2 in total anchorage displacement.

RESIN-GROUTED BOLTS

The resin-grouted bolts were installed using various grout lengths, starting at 2 ft and then increasing in 1-ft increments to full column length. The results indicated <0.2 in bolt yield, regardless of column length, when the bolt was subjected to 8 tons of load. The bolts yielded at an average of 10.5 tons, and displacement never exceeded 0.20 in (fig. 9). The resin bolts achieved good anchorage even in weak rock. One possible explanation could be that the grout bonded all the cracks where dilation was possible. This action produces a suspension effect, confining stretching to a short section of the bolt.

STRAIN-GAUGE BOLTS

Pull test results for the strain-gauge bolts were similar to those for the resin-grouted bolts. Small amounts of displacement occurred as a result of bolt elongation as opposed to anchor slippage. The 5-ft bolts were installed using 24- and 36-in-long resin columns. The gauge locations and resin columns are shown in figure 10. The setup enabled strains

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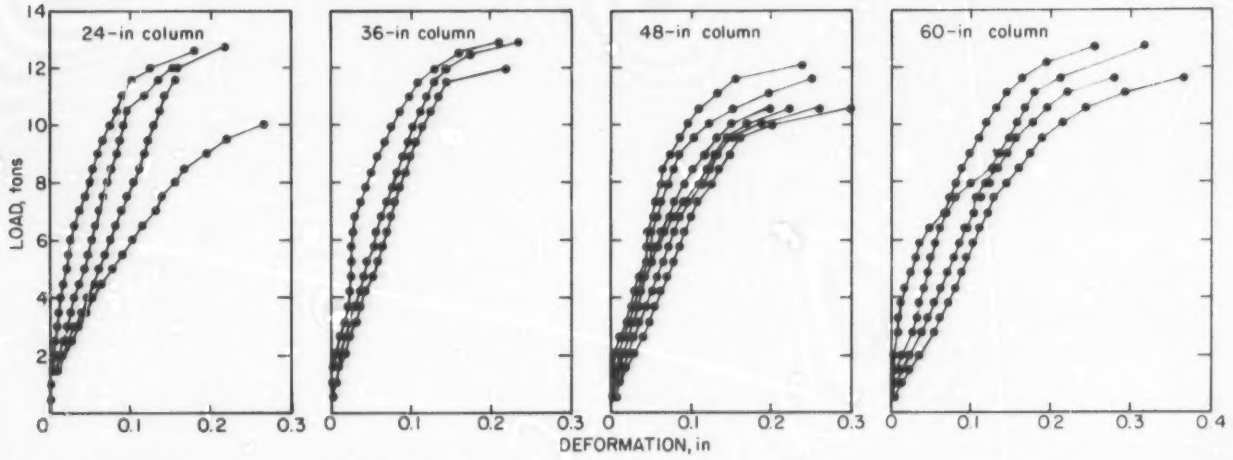

FIGURE 9. - Resin-grouted bolt pull test results. 5-ft bolts, 0.75 in diam, resin column lengths as shown.

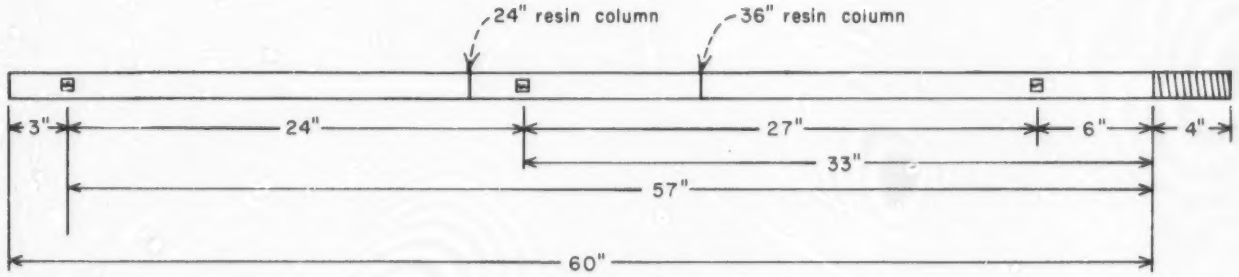

FIGURE 10. - Strain-gauge locations and resin columns in strain-gauge bolts.

to be recorded with varying amounts of grout. The strain gauges indicated distinctive stress patterns at the three instrumented levels.

The first type of field test was undertaken to determine strain gauge responses along the length of the bolt. A 5-ft bolt was installed with 2 ft of resin grout. This placed the grout 3 in above the gauge located at the 27-in level. The results, shown in figure 11, indicate that the gauges at the bottom and middle positions behaved practically identically. Also, the strains measured by these two gauges corresponded with the calculated strains predicted by the following equation:

$$P = E\varepsilon A,$$

where P = load, lb,

E = Young's modulus, psi,

ε = strain, 10^{-6} in,

and A = area of bolt, in^2 (the effective area for the strain gauge bolts in 0.55 in^2).

The gauge at the 57-in level was encased by 21 in of grout. Its response was approximately 6% of the strains measured in the unencapsulated gauges. This gauge response was highly influenced by end effects. The results do illustrate, however, how rapidly the loads dissipate when the grout column is encountered.

The second type of field test analyzed bolts that were installed with 3 ft of resin grout. Again, the bottom gauge was unencapsulated to check the system response. The middle and top gauges were

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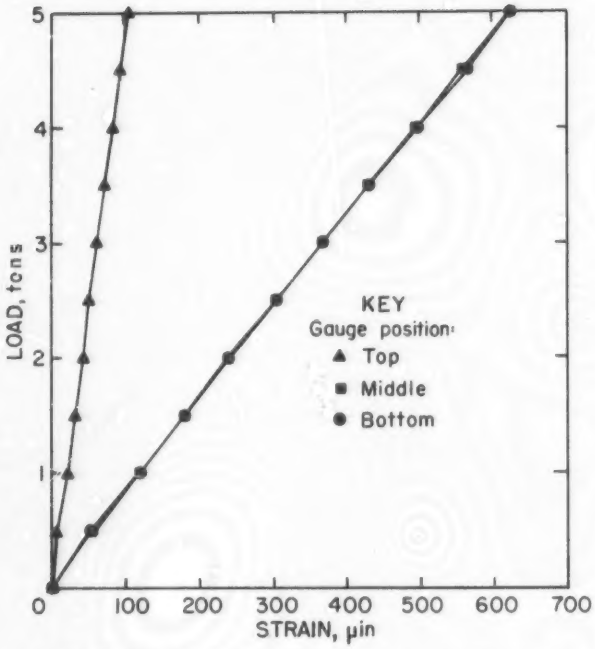

FIGURE 11. - Load-strain curve for strain-gauge bolt with 24-in resin column.

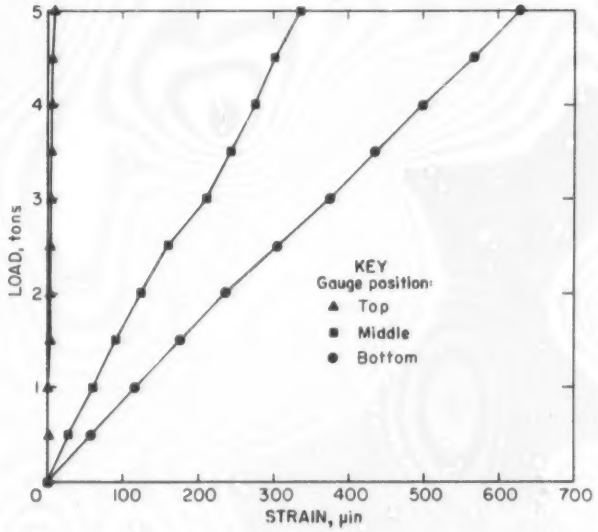

FIGURE 12. - Load-strain curve for strain-gauge bolt with 36-in resin column.

encapsulated in 9 in and 33 in of resin grout, respectively. The results, shown in figure 12, indicate that the bolt response, measured by the bottom gauge, is similar to the calculated response. The response of the middle gauge (encapsulated by 9 in of grout) was approximately 53% of the bottom gauge response. The top gauge, 33 in from the grout line, showed negligible amounts of strain. The test results illustrate that load transfer in the bolt system takes place almost totally within the bolt at the load levels tested.

REPRESENTATION OF PULL TEST BY FINITE ELEMENT MODEL

To obtain a better understanding of pull tests, field tests were used to verify the validity of a simple finite element computer model that provides a fundamental approach for designing rock anchor support systems for thick coal roofs (8-9). The model (fig. 13) simulates a 4-ft bolt with a 3/4-in diam, installed in a 1-in-diam hole. Stresses were applied to the end of the bolt in 100-psi increments, beginning with 100 psi and ending with 1,500 psi. A test run was also made at 5,000 psi on the bolt head. The model was three-dimensional axisymmetric with rotation about the centerline of the bolt. The properties of the various material components used in the analysis are listed in table 1.

TABLE 1. - Physical properties of materials used in finite element model

Property	Coal	Grout	Steel
Young's modulus (E) 10^6 psi..	0.50	0.30	30
Poisson's ratio (ν).	0.26	0.25	0.30
Density.....lb/in^3..	0.0486	0.0804	0.2604
Compressive strength (C).....psi..	1,000[1]	5,000	20,000
Angle of internal friction (φ)....°..	46	35	0
Tensile strength (τ) psi..	0	5,000	20,000

[1]Also tested at 1,500, 2,000, 3,500, 5,000, 7,500, and 10,000 psi.

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RESULTS OF FINITE ELEMENT ANALYSIS

The materials in the pull test model were assumed to be homogeneous and isotropic. Two types of cases were analyzed:

1. Hold all material components constant and vary the amount of load placed on the end of the bolt.

2. Keep the load on the end of the bolt constant and vary the compressive strength (shear strength) of the rock (coal) encompassing the tendon.

The computer analysis provided both center-point and nodal-point data for each element. Postprocessing of the original computer values revealed nearly linear dissipations of the applied loads through the length of the bolt. However, linear load dissipations did not correlate with the actual field measurements. To improve correlation and similitude, and to ensure compatibility with the original field measurements, the finite element model was slightly modified (10). The required modification included the addition of bolt displacements. The approximate bolt displacements, which were measured with a dial gauge during the field analysis, were added to the first one-third of the bolt length measured from the collar of the hole. The results, after this modification, compared favorably to the field data.

A typical representation of percent load versus distance is shown in figure 14. The plot shows how rapidly the load dissipates when applied to a fully grouted bolt. At a depth of 20 in, only 50% of the initial load is realized in

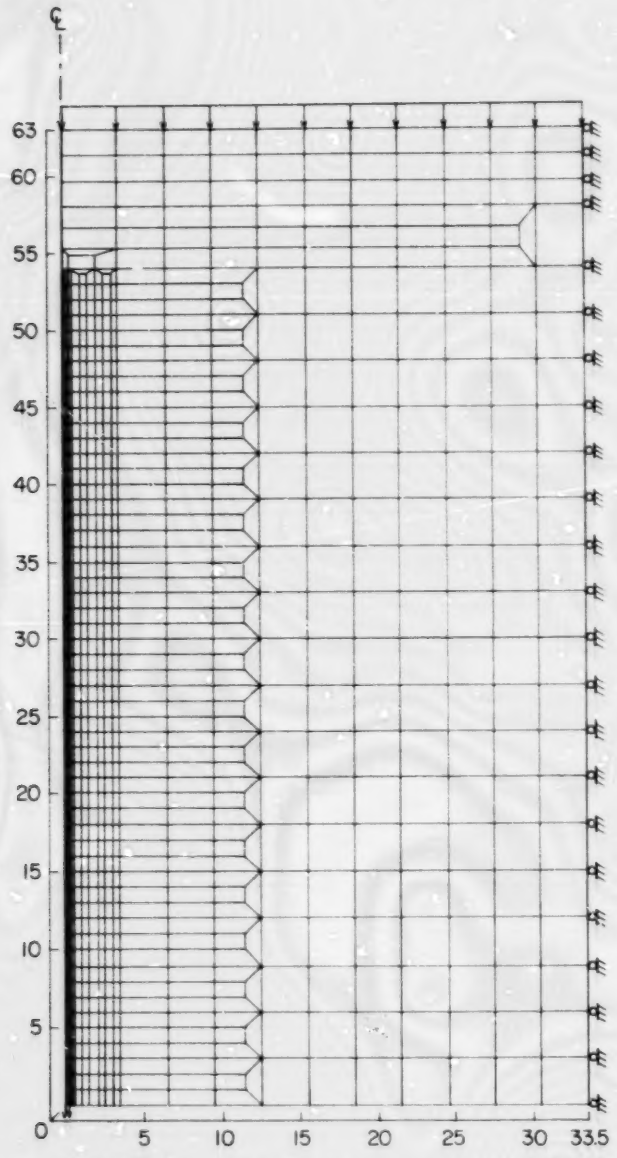

FIGURE 13. - Finite element model (showing model dimensions in inches).

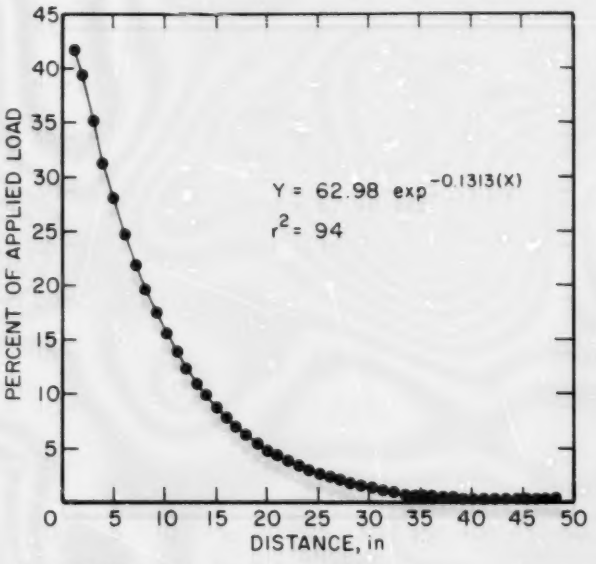

FIGURE 14. - Typical plot of percent of applied load versus bolt distance (r = coefficient of correlation).

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the bolt. The load dissipations were similar for all of the tested loads. It was shown in the field tests that the transfer of the load in the resin-grouted bolt system took place almost totally within the bolt at the load levels tested.

When load is applied to the bolt, the bolt stretches in the longitudinal direction and contracts in the traverse direction due to Poisson's effect. The contraction of the bolt will cause the bond to be broken between the bolt and the resin grout. If the loads are high enough, the contraction will cause the bolt to separate from the resin grout at the end. The length of this separation will increase with increasing loads. The amount of contraction in the anchor decays rapidly as the distance from the bolt head increases.

At a constant stress on the head of the bolt and at varying coal compressive strengths of 1,000, 1,500, 2,000, 3,500, 5,000, 7,500, and 10,000 psi, no significant changes in the stress distributions were observed. This was the result of the high values for the Young's modulus for the bolt as opposed to the low value for the coal (60:1). Safety factors were calculated, based on Mohr-Coloumb failure criteria, to determine the effect varying compressive strength values would have on the host rock. Results indicated that when the compressive strength is 2,000 psi or less, the safety factors approach critical levels. These safety factors indicate that the material 4 in up from the hole collar is in tension, which may cause failure.

CONCLUSIONS

All of the roof bolting systems tested met testing criteria required for thick top coal roofs with the exception of the type of expansion anchor bolts tested.

The finite element model and the strain-gauge bolts provided insights on load dissipation and anchorage behavior. It is recognized, however, that the results of the finite element study were dependent on the accurate determination of the host rock properties. Tests on fully instrumented pull-tested bolts in the same host rock as the model provided a validation of the numerical model.

The anchor load-transfer mechanism must be assessed to provide a complete picture of the stresses and strains around a fixed anchor.

It is believed that thick coal roofs can be fully supported in the bottom portion of the coal roof without anchoring in the immediate host rock.

REFERENCES

1. Karabin, G. J., and W. J. Debevec. Comparative Evaluation of Conventional and Resin Bolting Systems. MESA (now MSHA) IR 1033, 1976, 22 pp.

2. Karabin, G. J., and M. T. Hoch. An Operational Analysis of Point Resin-Anchored Bolting Systems, MSHA IR 1100, 1979, 14 pp.

3. _____. Contemporary Roof Support Systems Provide a Diversified Approach to Modern Ground Control. Paper in Proceedings, Annual Institute on Coal Mine Health and Safety Meeting. VA Polytech. Inst., 1980, pp. 249-268.

4. Kwitowski, A. J., and L. V. Wade. Reinforcement Mechanisms of Untensioned Full-Column Resin Bolts. BuMines RI 8439, 1980, 27 pp.

5. Brask, C. G., and H. Hamrin. New Type of Rockbolt Simplifies Rock Reinforcement Procedures. Atlas Copco, Sweden, 1983, pp. 1-17.

6. Nitzche, R. N., and C. J. Haas. Installation Induced Stresses for Grouted Roof Bolts. Int. J. Rock Mech., Min. Sci., and Geomech., v. 13, No. 1, 1976, pp. 17-24.

7. International Society for Rock Mechanics (Commission on Standardization of Laboratory and Field Test, Committee on Field Tests). Suggested Methods for

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Rockbolt Testing. No. 2, March 1974, pp. 1-16.

8. Bathe, K. A Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis (ADINA). Acoustics and Vibrations Lab., Mech. Eng. Dep., MIT, Cambridge, MA. Rep. 82448-1 Sept. 1975, p. 360.

9. Yap, L. D., and A. A. Rodger. A Study of the Behavior of Vertical Rock Anchors Using the Finite Element Method. Int. J. Rock Mech., Min. Sci., and Geomech., v. 21, No. 2, 1984, pp. 47-61.

10. Serbousek, M. O., and S. P. Signer. Load Transfer Mechanics in Fully Grouted Roof Bolts. Pres. at 4th Conference on Ground Control in Mining, Morgantown, WV, July 22-24, 1985, 11 pp.; available from M. O. Serbousek, U.S. Bureau of Mines, Spokane Research Center, Spokane, WA.

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APPENDIX.--TORQUE-TENSION RATIO TESTS

Torque-tension ratio tests determine the amount of torque necessary for the proper installation of mechanical expansion anchor and combination bolts. The test procedure requires that a calibrated hydraulic U-cell be installed between the bearing plate and the mine roof. The bolt is then tightened by turning its head with a torque wrench. The values of the torque wrench are recorded in conjunction with the value on the U-cell. When the value on the U-cell drops, the maximum anchorage capacity of the bolt system has been attained. Bolts should then be tensioned to 50% to 70% of the yield strength of the bolt or 50% to 70% of the anchorage capacity of the material, whichever is less. The recommended torque-tension ratio is 50 lb tension per foot pound of torque for bolts without hardened washers or 60 lb tension per foot pound of torque with hardened washers.

An example follows: Find the torque range for a 5/8-in grade 55 bolt with no hardened washer when the rock anchorage capacity is 15,000 lb. The yield strength for a grade 55 bolt is 12,400 lb, which is less than the anchorage capacity. Therefore, the yield strength is used for design purposes, as shown below.

Lower-limit calculation

$$\begin{array}{r} 12{,}400 \text{ lb} \\ \times\ 50\% \\ \hline 6{,}200 \text{ lb} \end{array}$$

$$\frac{6{,}200 \text{ lb}}{50 \text{ lb/lbf}} = 124 \text{ lbf·ft torque}$$

Upper-limit calculation

$$\begin{array}{r} 12{,}400 \text{ lb} \\ \times\ 70\% \\ \hline 8{,}680 \text{ lb} \end{array}$$

$$\frac{8{,}680 \text{ lb}}{50 \text{ lbf/ft}} = 174 \text{ lbf·ft torque}$$

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